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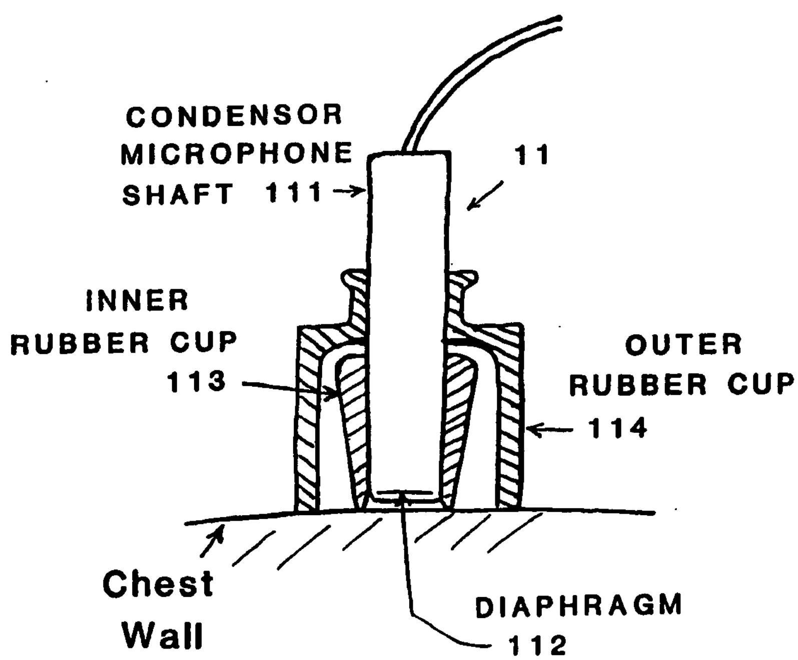
(54) Title: DYNAMIC SPECTRAL PHONOCARDIOGRAPH



(57) Abstract

A method of generating a spectral phonocardiogram which summarizes time dependent changes in the heart sounds throughout the heart cycle. The method is based on the projection of spectral surface of the Fourier transform of heart sounds as a function of time and is a useful diagnostic tool for both a cardiologist and a general practitioner. Permanent copies of the spectral phonocardiograms can provide useful records for monitoring the development of heart disease in a given individual.

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DYNAMIC SPECTRAL PHONOCARDIOGRAPH

BACKGROUND OF THE INVENTION

The present invention relates to phonocardiograms and in particular to an improved technique for phonocardiograms.

The prior art has noted the potential utility of computer-base Fourier analysis of heart sounds for diagnostic purposes. Although such prior art has demonstrated the feasibility of identifying certain heart sounds and recognizing murmurs, the previous work along these lines has largely been limited by excessive computing time required for Fourier analysis and a limitations on sensitivity, dynamic range, frequency range and resolution, and by noise level of available sound detection and recording apparatus.

SUMMARY OF THE INVENTION

The present invention is directed to a system for projections of spectral surfaces of the Fourier transform of heart sounds in real time on a video monitor while the physician is listening to the same sounds. This technique would result in a dynamic Spectral Phonocardiogram (SPG) which in turn would provide a sensitive method of picking out irregular sound patterns at different portions of the heart cycle as a function of frequency. Because such displays would extend the sensitivity of the human ear and supplement that sensitivity with the ability of the human eye to perform pattern recognition, it would also provide a useful supplementary auscultation tool for cardiologists, for those assessing a patient's general health, and for those learning the art of physical diagnosis. With the current availability of the echocardiogram at most major hospitals, the most immediate practical application of this method and apparatus would be to provide a permanent record of the heart sound spectra which could be used comparatively to monitor the progression of heart disease in a given patient.

These and other features and advantages of the present invention will be seen from the following detailed description of the invention, taken with the attached drawings, wherein:

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a schematic representation of the system according to the present invention;

Figure 2 is a detailed view of the apparatus for placing a microphone on a patient's body in accordance with the method of the present invention;

Figure 3 is a schematic of the apparatus for carrying out the method according to the present invention;

Figure 4 is a spectral phonocardiogram at the apex with an A-weighting function and a normal heart with a split first sound;

Figure 5 is a spectral phonocardiogram of heart sounds at the apex of the heart with A-weighting and showing a grade 2 mitral murmur; and

Figure 6 is a spectral phonocardiogram using a log plot of the heart sound amplitudes at apex with an A/2 weighting and showing a mitral murmur.

DETAILED DESCRIPTION OF THE INVENTION

Referring now to Fig. 1, the system according to the present invention for carrying out a spectral phonocardiogram includes the video portion comprising microphones 11 and 12 placed at different regions of the heart and connected to the circuitry 20 for obtaining projections of spectral surfaces of Fourier transforms of the heart sounds in real time on a video monitor. Box 20 in Fig. 1 comprises elements 21-30 shown in Fig. 3.

The audio portion of the dynamic spectral phonocardiogram is obtained by using stethescope 40 which has the end applied also to the vicinity of the heart of a patient.

EXAMPLE

Measurements were made using two Sennheiser model MKH104 condensor microphones 11, 12 with frequency response curves which were flat within about 1-dB from about 5 Hz to well over 20-kHz. Data were recorded digitally using a Sony PCM F1 A-to-D converter 21 and video cassette recorder 22. Data were taken simultaneously from the two microphones, with one placed at the base of the heart (feeding the left channel of the recorder) and the other placed at the apex (feeding the right stereo channel). Listening to the heart sounds in stereophonic playback while looking at the waveform displays provided a very helpful aid in identifying the physical location of unusual heart sounds such as the murmur from mitral insufficiency. Under these conditions, the heart sounds appear to be spread out spatially with remarkable clarity. For example, because the sensitive diaphragm of each microphone is no bigger than the diameter of a typical heart valve, positioning the microphones over the tricuspid and mitral valve locations and listening to the two sounds with stereophonic headphones, permits identifying which of these valves closes first in the case of a split first sound.

During measurements, each microphone was housed in a double rubber cup as shown in Fig. 2. The inner cup 113 was about 3/4" in diameter and suspended the diaphragm 112 of the microphone about ¼" above the chest, sealing the small enclosed volume from the outside and providing good acoustic coupling for the microphone to the chest wall. The outer rubber cup 114 was about 3" in diameter and provided a double acoustic shield from outside noises, as well as increasing the mechanical stability in positioning the microphones. Each cup had a hole drilled in the center which fit snuggly about the cylindrical shaft 111 of the microphone housing.

Although these cups provided adequate acoustic isolation so that the microphones could be positioned and

held lightly in place with the fingers, broad elastic belts fastened by buckles (not shown) held the microphones in place during extended recordings of heart sounds. In practice, each recording was made for a period of several seconds in order to provide representative data and to insure that sections of data would be recorded which were relatively free of digestive and breathing noises. The arrangement used provided remarkable isolation from background room noise.

Even allowing 6-dB "headroom" in recording the peak signals, the outside acoustic and electrical noise levels in the digital recordings were typically 85- to 90-dB below the maximum signal at frequencies extending from 20-kHz down to about 5Hz. In principle, a limiting signal-to-noise ratio of about 99-dB should be obtainable from the 16-bit-per-sample digital recording system used. The recorded data were analyzed with a hard-wired 12-bit FFT processor 25 which could convert successive 1024-point time samples into 400-point displayed frequency samples at the rate of 25 per second. In order to avoid spurious frequency components being generated from the quasi-continuous waveforms being studied, a Hanning weighting function 23, 24 was used on the time window. This window consists of a smoothly varying multiplicative function which forces the original signal amplitude to zero at the start and end of the sample period without appreciably distorting the spectral amplitudes of real signals that are periodic in the sample period. Without this type of weighting function, nonperiodic signals in the sample interval from the microphone can result in very large, erroneous spectral components. As applied to the first and second heart sounds where strong low frequency components are present, absence of such a weighting function often results in a large, quasi-exponentially decaying pedestal of spurious frequency components on Log plots of the Sound Pressure Level vs

Frequency, which components extend far beyond the bandwidth of the actual signal.

Although the FFT processor can handle spectra of up to 10-kHz frequency bandwidth in real time, a useful compromise between frequency resolution and observed bandwidth in the present study was found to be one in which a 1-kHz spectral range was displayed with a limiting frequency resolution of 2.5 Hz (obtained from a 400-msec Hanning window) at the rate of 10 per second.

Time-dependent changes in the spectral distribution of heart sounds can be used to provide a more sensitive and stable set of visual patterns for such identification purposes by themselves. Such time-dependent changes in the spectra throughout the heart cycle can be best illustrated by plotting a surface of the Fourier amplitude components. Such a spectral surface plot, or Spectral Phonocardiogram (SPG), can summarize in one display all of the available information obtainable from sound measurements throughout the heart cycle. A permanent record of the SPG taken in this way with the microphone at standard locations on the chest would provide useful comparative data for monitoring the development of heart disease in a given individual.

Figure 4 illustrates a linear display of such a spectral surface, or Spectral Phonocardiogram (SPG), taken at the apex of a normal heart (with split first sound) over four successive beats using A-weighting which is a filter which replicates the loss in the human ear at low frequencies at typical heart sound intensities - e.g., the so called "A-weighting" widely used in sound level measurements. A good replica of the A-weighting curve was made using two 1/3 octave graphic equalizers 26, 27 and 28,29 in Fig. 3 made by the MXR company, each of which contributed half of the total loss in dB for the A-weighting curve as a function of frequency. By placing the two units

in series, one can quickly switch among: unfiltered transmission, referred to as "A/2 weighting" (one filter inserted), and full "A-weighting" (both filters inserted). Creating the illusion of three dimensions in this type of plot is discussed in Chapter 3 of the Bennett, Scientific and Engineering Problem Solving with the Computer, Prentice-Hall (Englewood Cliffs, 1976). In the present case the altitude of the surface is proportional to the linear rms amplitude of the Fourier components, frequency (from 2.5-Hz to 1000-Hz) is displayed along the horizontal axis, and time (in tenths of a second) is displayed going diagonally towards the final horizon (at t = 3.8 secs) for a continuous stream of data.

For the normal heart, data of this type appear to be moderately coherent from one beat to the next. At the low frequency end of the SPG in Fig. 4, one can see a very clear transition from the spectrum of the first sound to that for the second sound. The spectral components and region of transition from first to second sound have a very similar distribution for each beat. In contrast, the SPG shown in Fig. 5 for the person with the holosystolic murmur exhibits spectral components which are much more incoherent. There is a substantial randomness in the frequency components in going from one beat to the next. In addition, one can clearly see the effects of randomness in each individual heart beat in the spectral components from 100- to 1000-Hz which arise from turbulence created by mitral prolapse. The scraping or rasping noise one hears through the stethoscope obviously corresponds to the randomness in this portion of the spectral distribution.

In addition, one needs a logarithmic plot to display grade data because of the inherent logarithmic response of the ear to loudness. The use of a Log scale in the SPG would also permit expressing the ratio of peak intensities by a simple linear measurement from a vertical

scale calibrated in dB. 10-dB steps in the audible spectral intensity would provide a good way to define the boundaries in grade levels because psycho-acoustic studies have shown that people generally associate a doubling in loudness with a 10-dB increase in sound pressure level.

Fig. 6 provides a Log plot of the rms spectral amplitudes of heart sounds obtained at the apex for the mitral murmur using A/2-weighting for four successive heart beats. The vertical scale has a full range of 60-dB in this plot and one can clearly see the strong components at very low frequencies. The location of the cut-off base plane on the SPG can be adjusted at different heights to optimize the ease of pattern recognition and to accomplish the murmur grade measurement itself. For example, one could move up the cut-off plane until the murmur in the 300- to 1000-Hz spectral region just disappeared visually. At that point one could read the peak height of the low frequency maximum above the murmur directly from the vertical scale in dB.

It will be appreciated that the instant specification, example and claims are set forth by way of illustration and not limitation, and that various modifications and changes may be made without departing from the spirit and scope of the present invention.

WHAT IS CLAIMED IS:

1. A method of producing a dynamic spectral cardiogram for picking out irregular sound patterns at different portions of the heart cycle as a function of frequency, comprising the steps of:

a. producing a real time audio representation of a patient's heart sounds; and

b. producing video display of the same heart sounds by generating projections of spectral surfaces of Fourier transforms of the heart sounds in real time.

2. The method according to claim 1, wherein the real time audio representation is produced by placing a stethoscope in the vicinity of a patient's heart.

3. The method according to claim 1, wherein the video display is produced by placing at least one microphone in the vicinity of a patient's heart to produce an analog output signal corresponding to the heart sounds, converting the analog output signal of the microphone to a digital signal, performing a fast Fourier transform on the digital signal and displaying the transforms as spectral surfaces on a display.

4. The method according to claim 3, wherein step of producing the video display further comprises applying a Hanning weighting function to the digital signals and applying a second weighting function to the fast Fourier transform before displaying same.

5. The method according to claim 4, wherein the second weighting function is an A/2 weighting function.

6. The method according to claim 4, wherein the weighting function is an A weighting function.

7. A method of producing a spectral cardiogram, comprising:

generating projections of spectral surfaces of Fourier transforms of heart sounds, and

displaying the spectral surfaces.

8. The method according to claim 7, wherein the projections are generated by placing at least one microphone in the vicinity of a patient's heart to produce analog output signals corresponding to the heart sounds, converting the analog output signal to a digital signal, performing a fast Fourier transform on the signal.

9. The method according to claim 8, wherein the step of generating the projections further comprise storing the digital signal on a video tape recorder.

10. The method according to claim 7, wherein the step of displaying comprising displaying on a video monitor.

11. The method according to claim 8, wherein the step of generating projections further comprises applying a Hanning weighting function to the digital signals and applying a second weighting function to the fast Fourier transform before displaying same.

12. The method according to claim 8, wherein the step of generating projections further comprises the second weighting function is an A/2 weighting function.

13. The method according to claim 8, wherein the step of generating projections further comprises the weighting function is an A weighting function.

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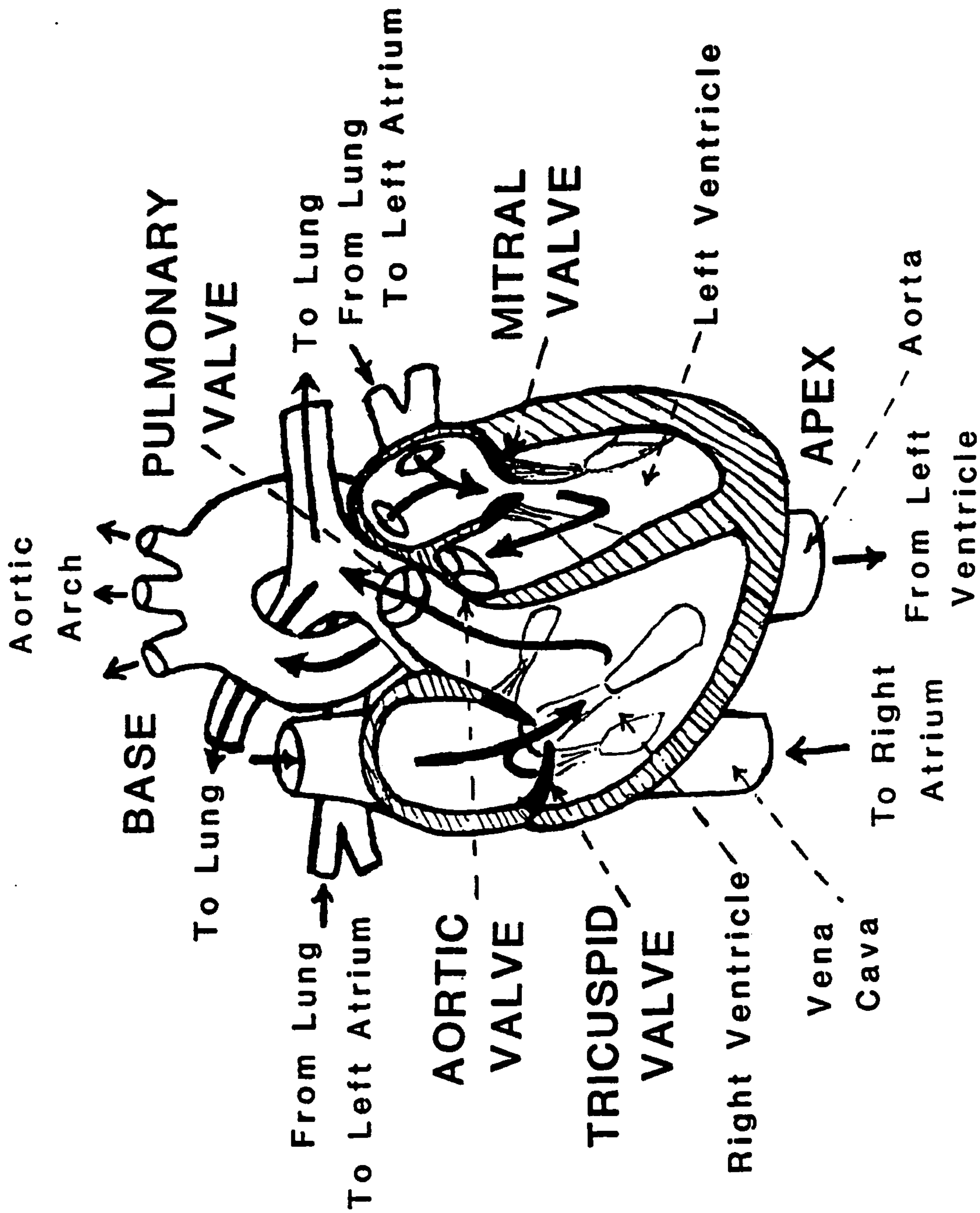
Aortic
Arch
PULMONARY
VALVE
To Lung
From Lung
To Left Atrium
MITRAL
VALVE
Left Ventricle
APEX
Aorta
From Left
Ventricle
BASE
To Lung
From Lung
To Left Atrium
AORTIC
VALVE
TRICUSPID
VALVE
Right Ventricle
Vena
Cava
To Right
Atrium

Fig. 1

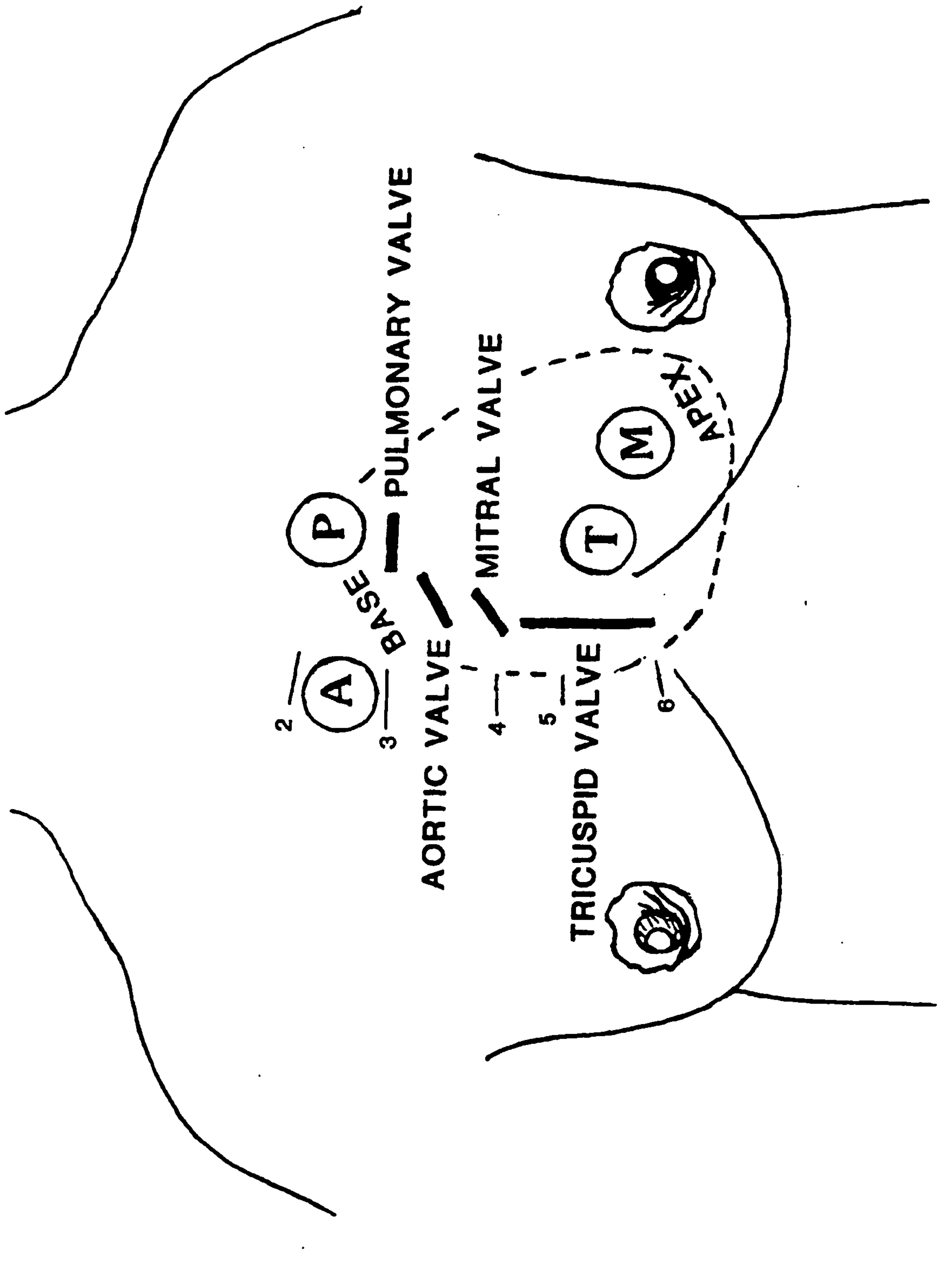
A
P
T
M
BASE
APEX
PULMONARY VALVE
MITRAL VALVE
AORTIC VALVE
TRICUSPID VALVE
2
3
4
5
6

Fig. 2

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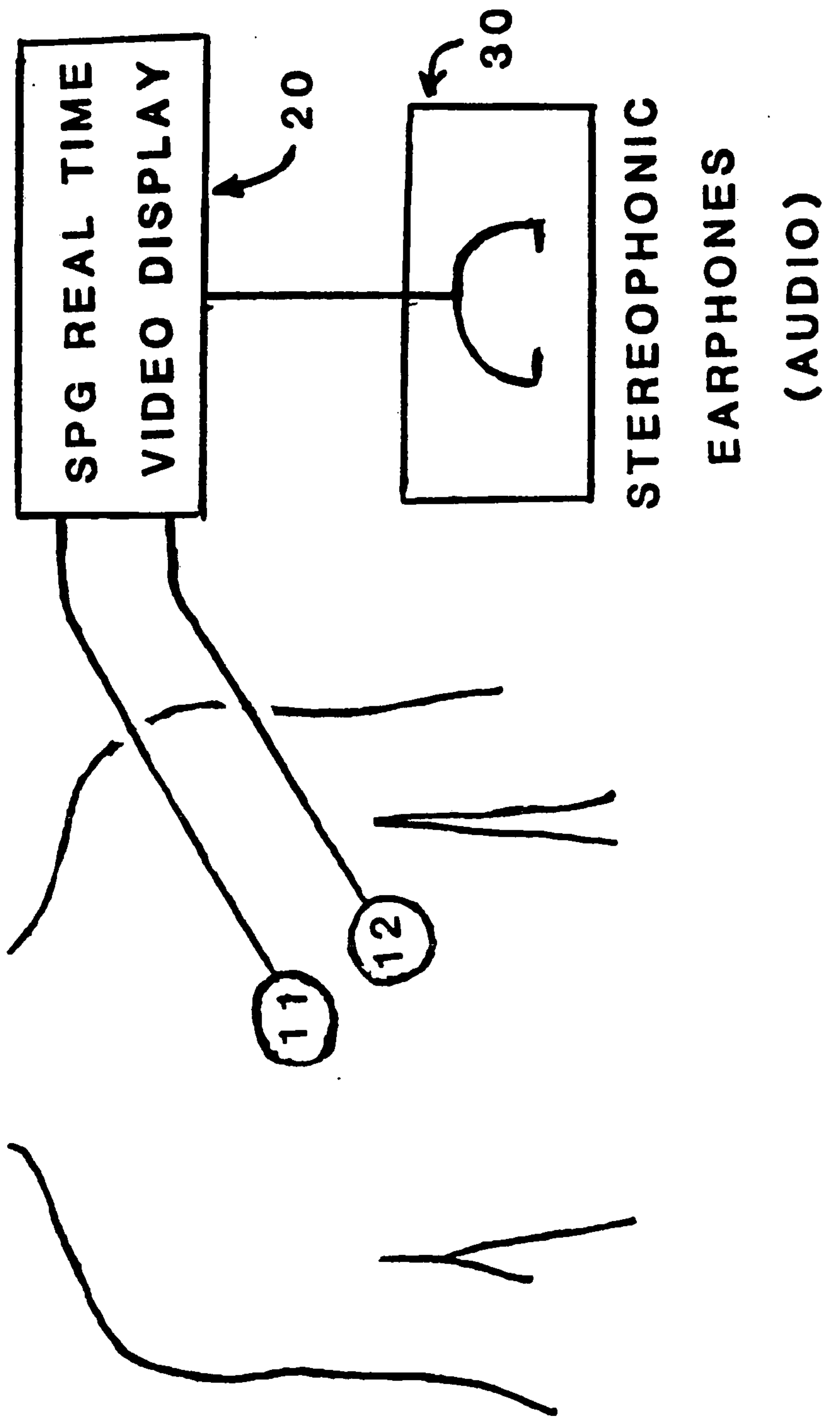
SPG REAL TIME
VIDEO DISPLAY
20
30
STEREOPHONIC
EARPHONES
(AUDIO)
11
12

Fig. 3

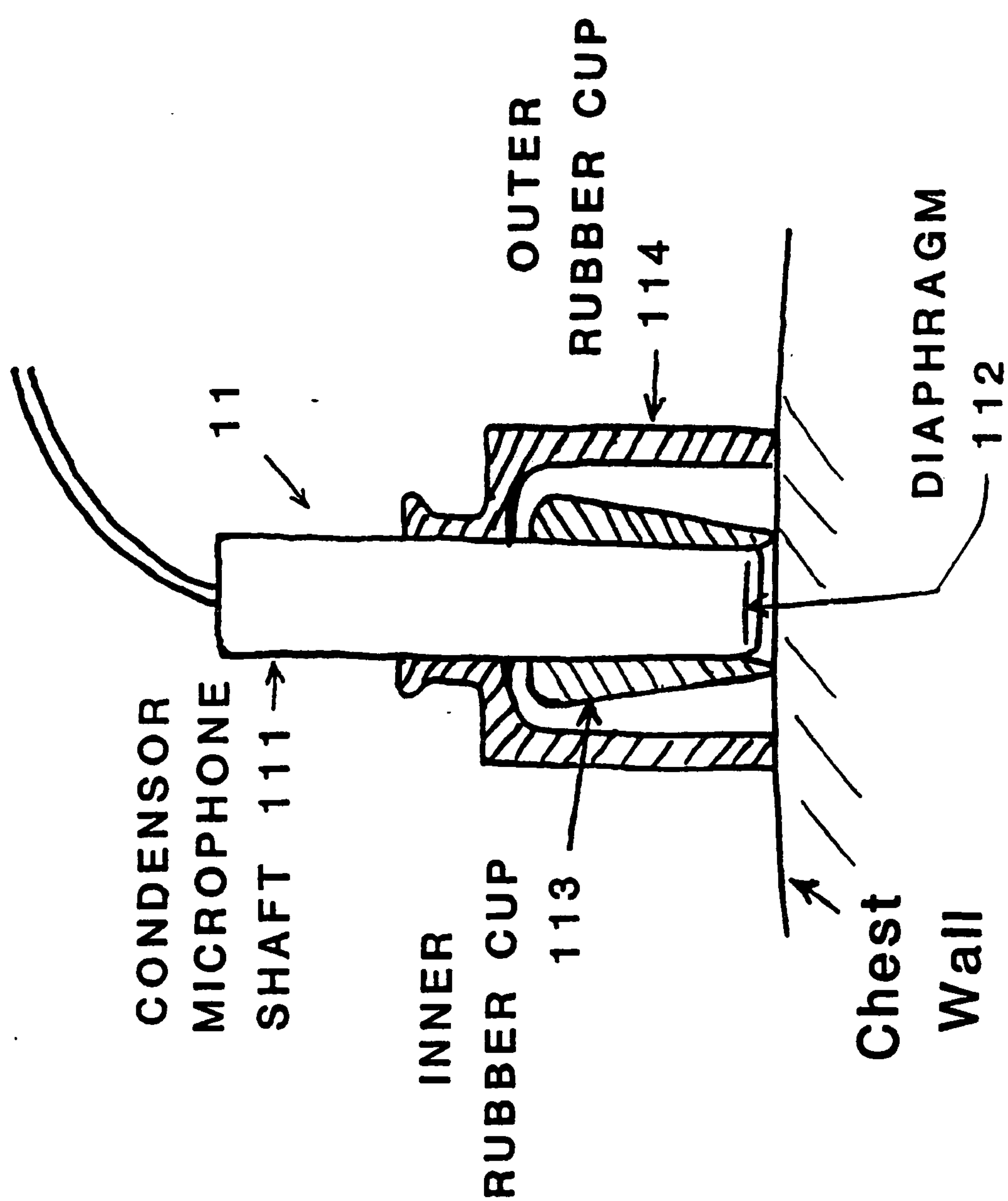
CONDENSOR
MICROPHONE
SHAFT 111
INNER
RUBBER CUP
113
OUTER
RUBBER CUP
114
11
DIAPHRAGM
112
Chest
Wall

Fig. 4

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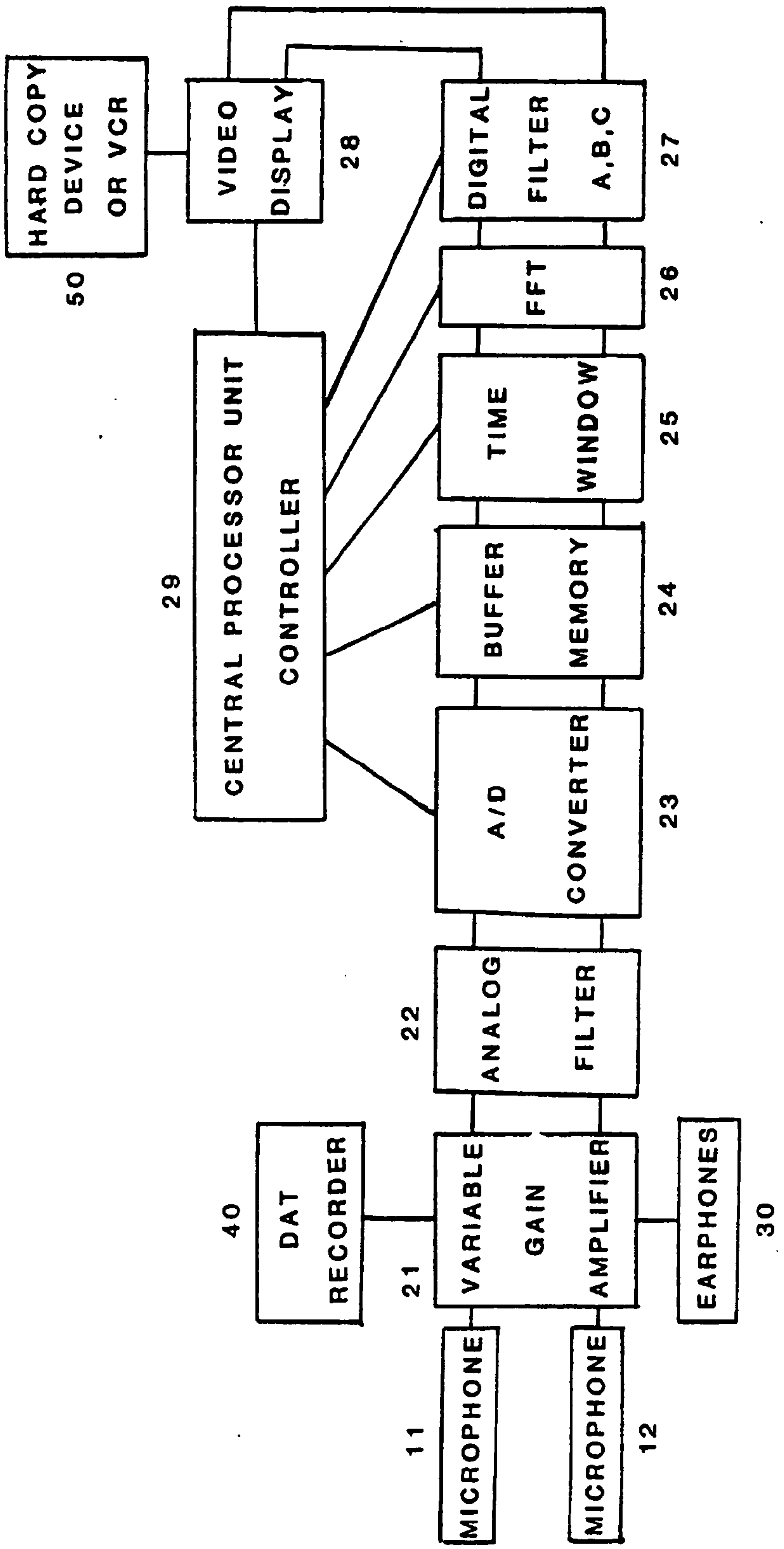
HARD COPY DEVICE OR VCR
50
VIDEO DISPLAY
28
DIGITAL FILTER A,B,C
27
FFT
26
TIME WINDOW
25
BUFFER MEMORY
24
A/D CONVERTER
23
CENTRAL PROCESSOR UNIT CONTROLLER
29
ANALOG FILTER
22
DAT RECORDER
40
VARIABLE GAIN AMPLIFIER
21
EARPHONES
30
MICROPHONE
11
MICROPHONE
12

Fig. 5

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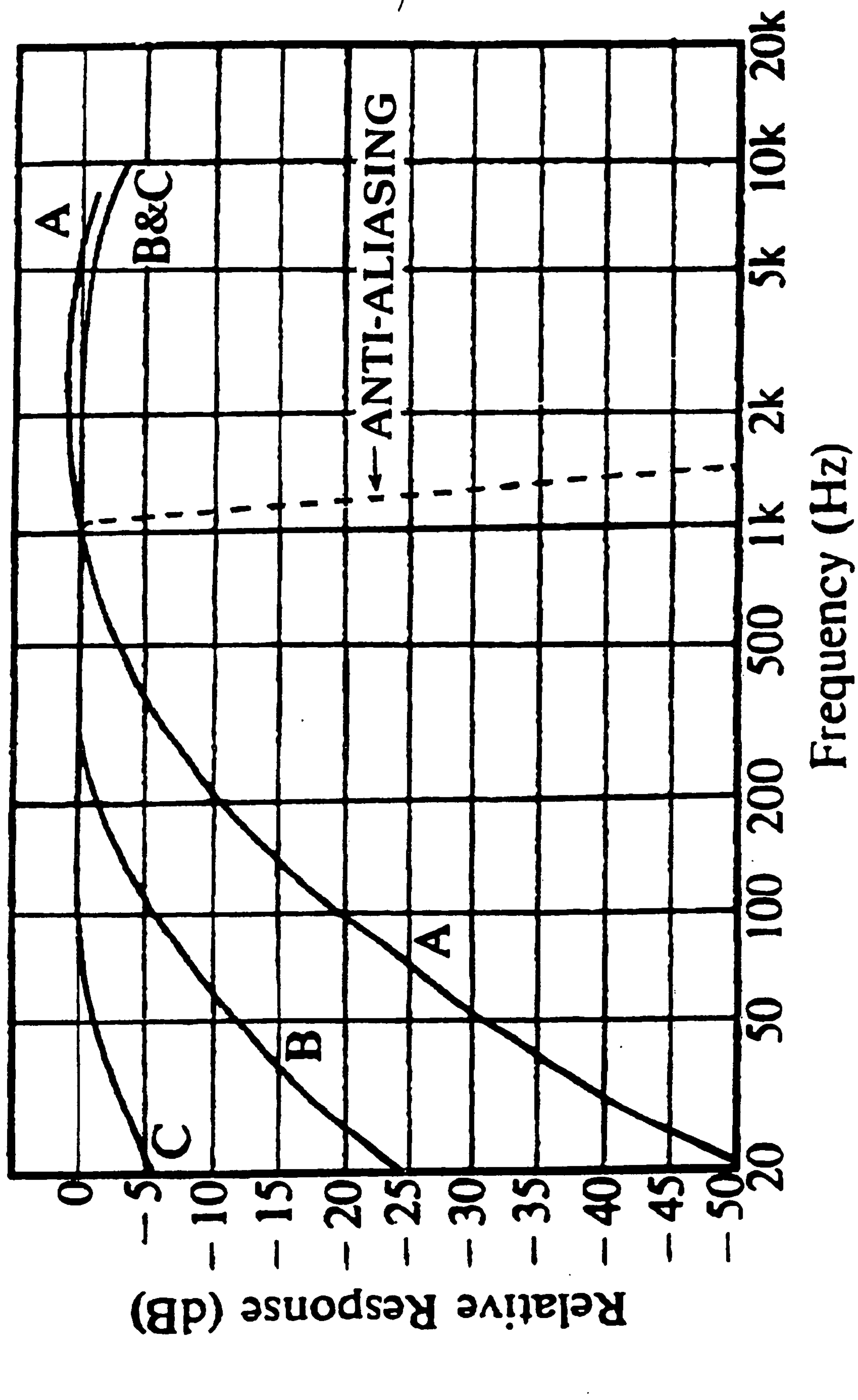
Relative Response (dB)
0
–5
–10
–15
–20
–25
–30
–35
–40
–45
–50
Frequency (Hz)
20
50
100
200
500
1k
2k
5k
10k
20k
A
B&C
A
B
C
←ANTI-ALIASING

Fig. 6

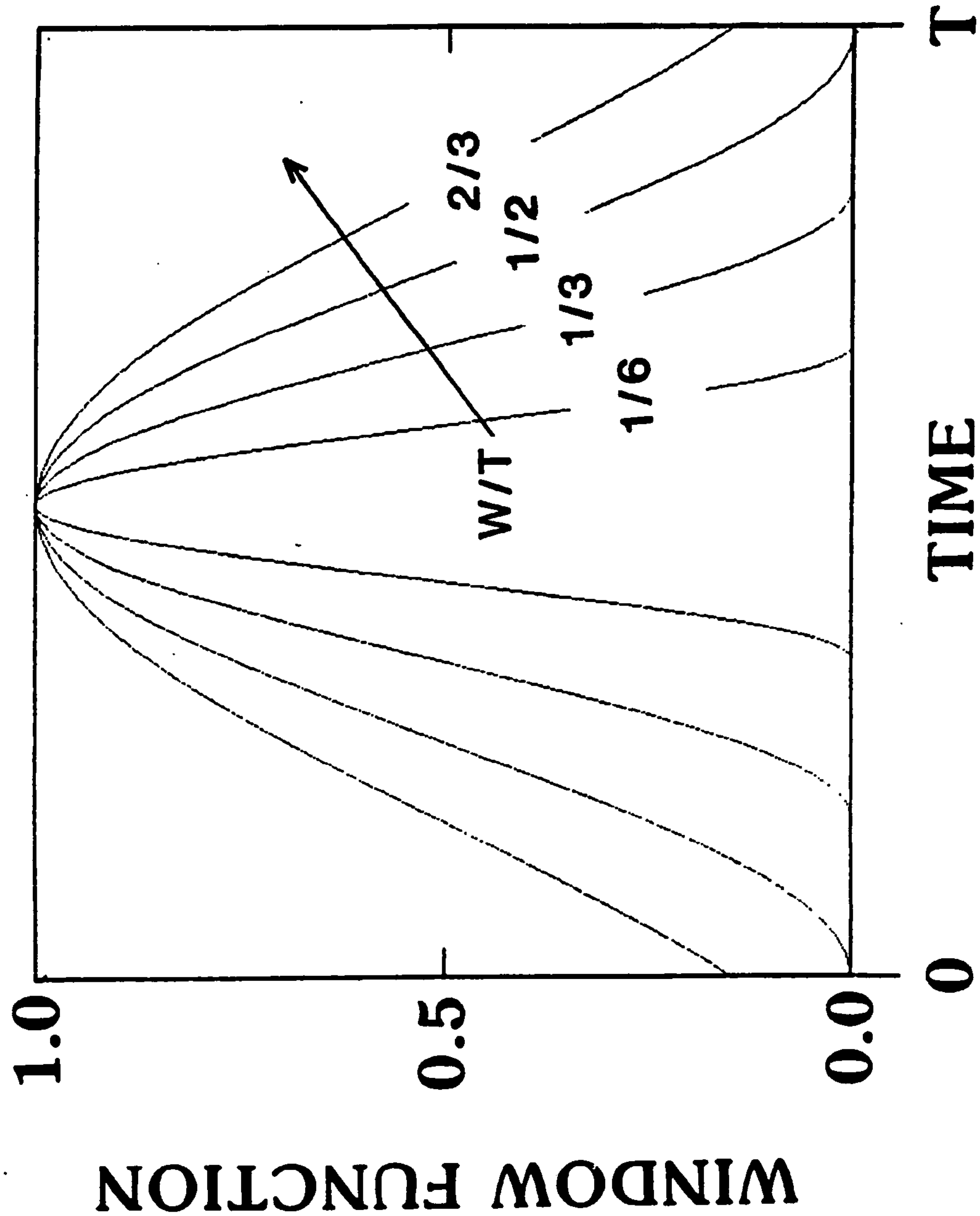

Fig. 7

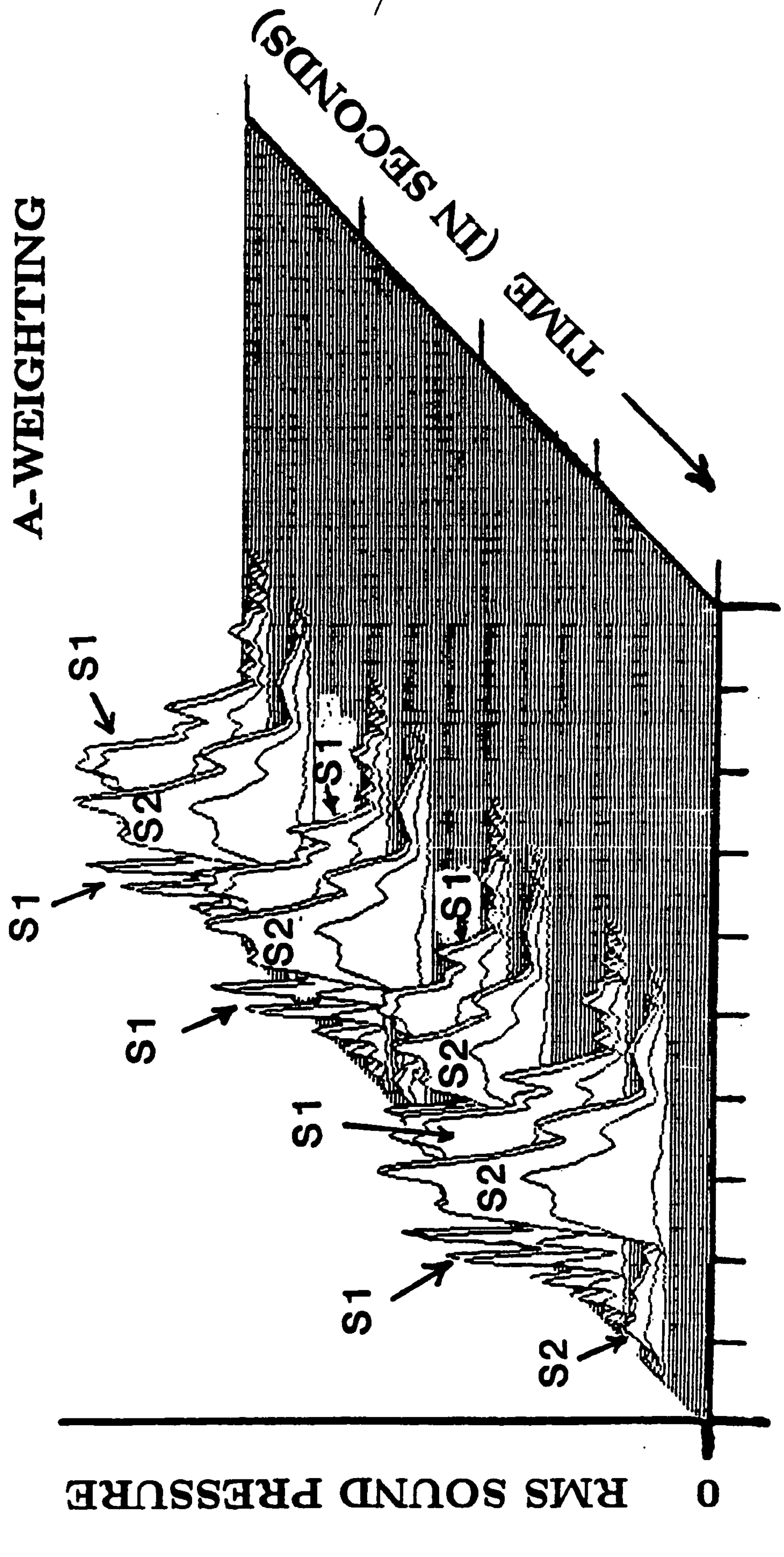
A-WEIGHTING
TIME (IN SECONDS)
RMS SOUND PRESSURE
0
FREQUENCY (IN HZ)
0
1000
S1
S2

Fig. 8

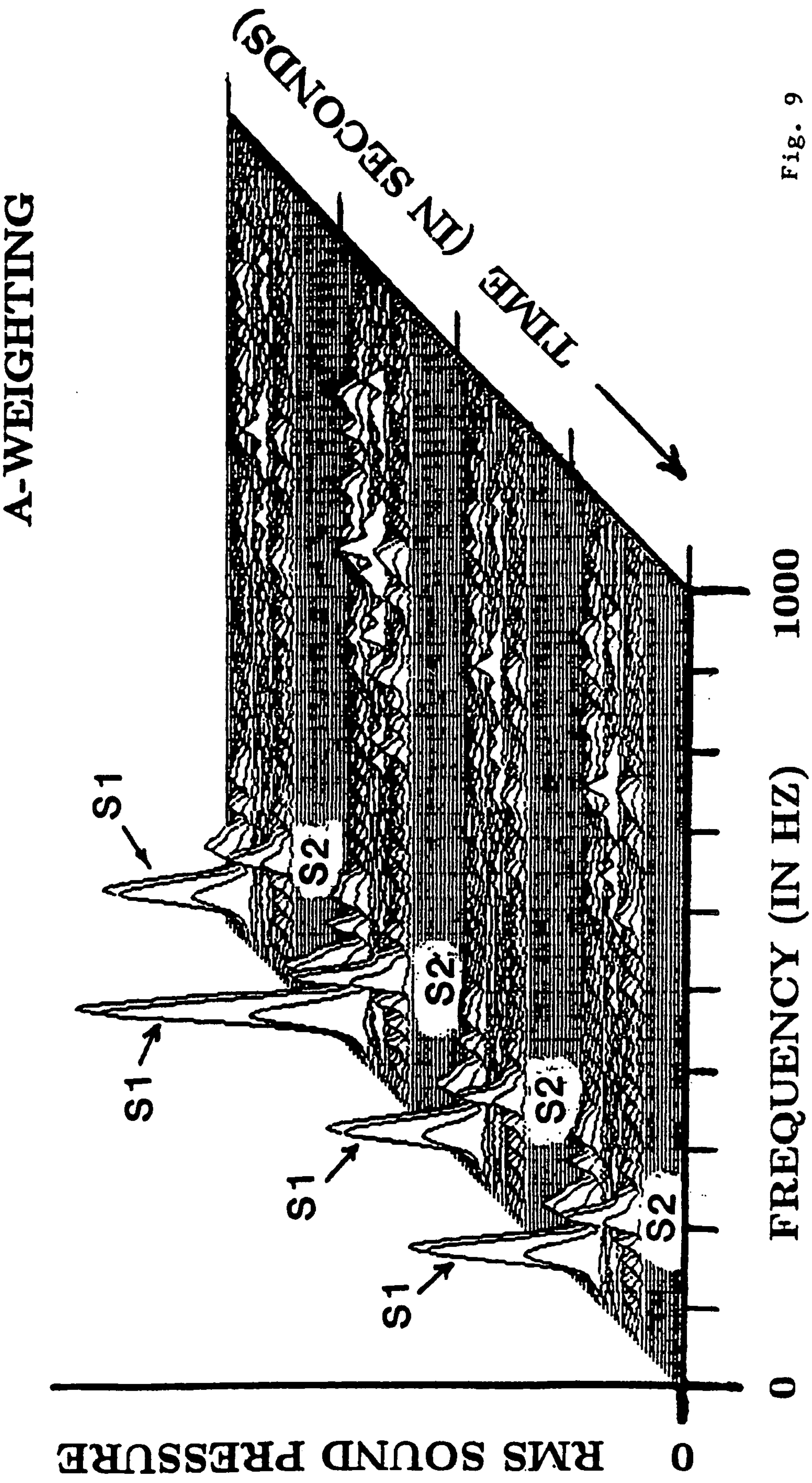
A-WEIGHTING
TIME (IN SECONDS)
S1
S2
1000
0
FREQUENCY (IN HZ)
RMS SOUND PRESSURE

Fig. 9

10/12

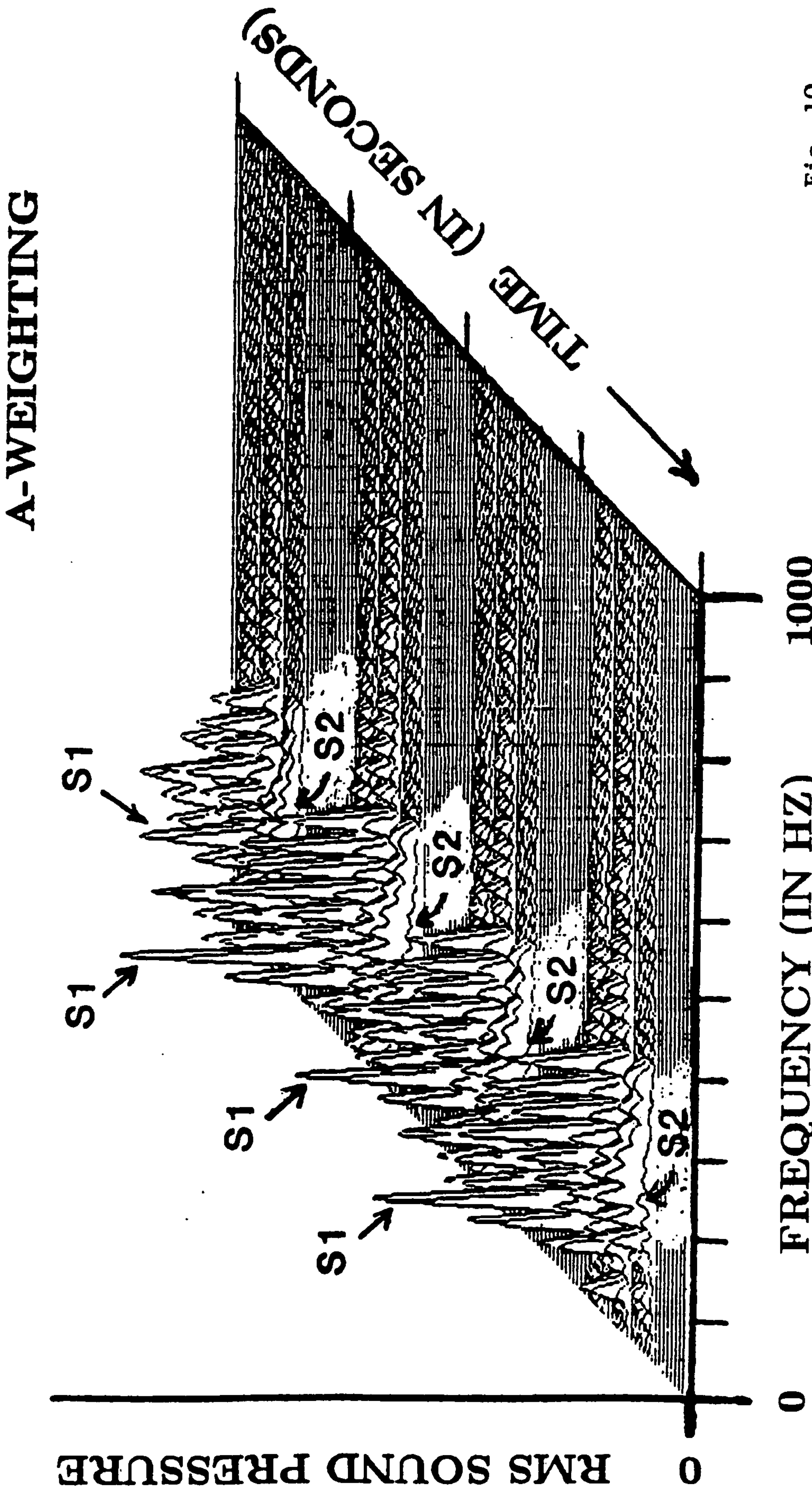
A-WEIGHTING
TIME (IN SECONDS)
S1
S2
0
1000
FREQUENCY (IN HZ)
0
RMS SOUND PRESSURE

Fig. 10

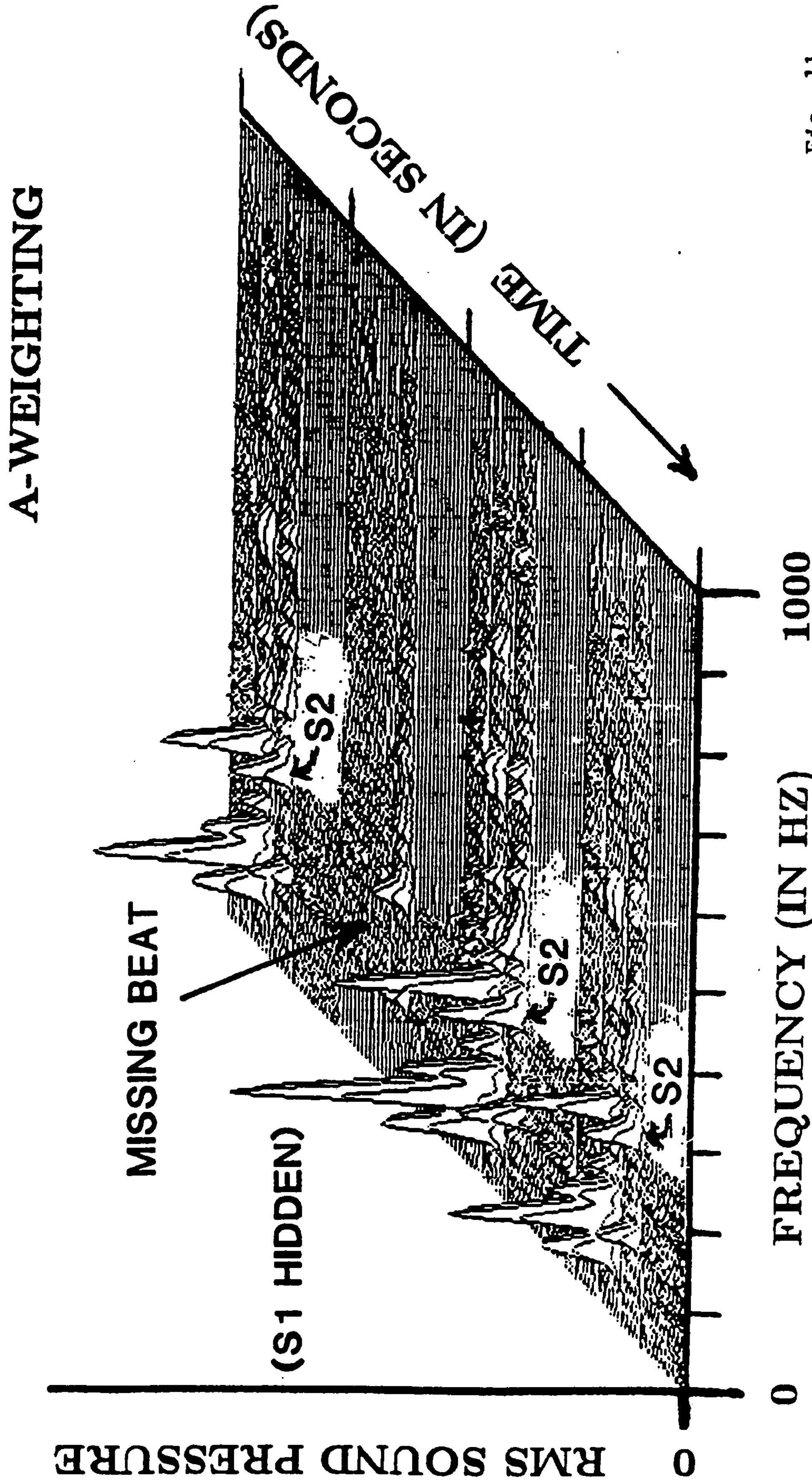
A-WEIGHTING
MISSING BEAT
(S1 HIDDEN)
S2
S2
S2
TIME (IN SECONDS)
RMS SOUND PRESSURE
0
0
1000
FREQUENCY (IN HZ)

Fig. 11

12/12

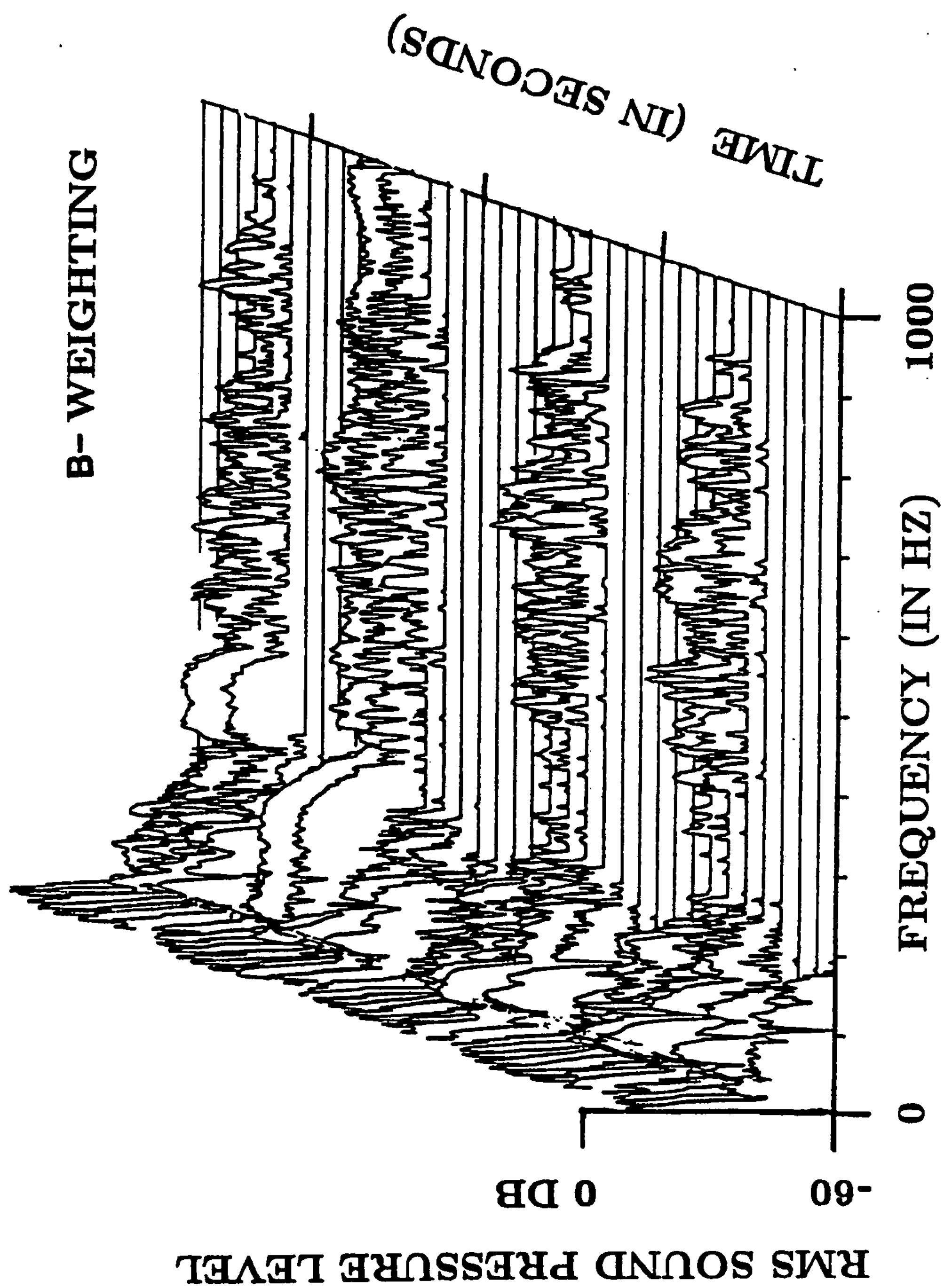
B- WEIGHTING
TIME (IN SECONDS)
1000
0
FREQUENCY (IN HZ)
0 DB
-60
RMS SOUND PRESSURE LEVEL

Fig. 12

INTERNATIONAL SEARCH REPORT

International Application No. PCT/US90/00510

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all) [6]

According to International Patent Classification (IPC) or to both National Classification and IPC

INT. Cl.(5) A61B 5/02
U.S. Cl. 128/715

II. FIELDS SEARCHED

Minimum Documentation Searched [7]

Classification System	Classification Symbols
U.S.	CLASS 128, SUBCLASSES 699,710

Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched [8]

III. DOCUMENTS CONSIDERED TO BE RELEVANT [9]

Category *	Citation of Document, [11] with indication, where appropriate, of the relevant passages [12]	Relevant to Claim No. [13]
Y	US,A, 4,458,693 (BADZINSKI ET AL.) 10 JUNE 1984. See the entire document.	1-13
Y	US,A, 4,792,145 (EISENBERG ET AL.) 20 DECEMBER 1988. See the entire document.	1-13
Y	US,A, 4,413,630 (ANDERSON ET AL.) 08 NOVEMBER 1983. See the entire document.	1-13
Y	US,A, 4,549,551 (DYCK ET AL.) 29 OCTOBER 1985. See the entire document .	1-13
Y	US,A, 4,700,712 (SCHMID) 20 OCTOBER 1987. See the entire document.	1-13
Y	US,A, 3,442,264 (LEVITT) 06 MAY 1969. See the entire document.	1-13

* Special categories of cited documents: [10]

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"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

IV. CERTIFICATION

Date of the Actual Completion of the International Search	Date of Mailing of this International Search Report
05 MARCH 1990	27 APR 1990
International Searching Authority	**Signature of Authorized Officer**
ISA/US	G. MANUEL G. Manuel